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(54) A hermetically sealed semiconductor inertial sensor

(57) An inertial sensor (105) having a sensing element (115) formed on one surface of a chip (110) of semiconductor material and movable with respect to the chip (110), the sensing element (115) being enclosed in a sealed hollow structure (125), in which the hollow structure (125) includes a metal wall (130) disposed on the said surface around the sensing element (115) and a closure plate (135) fixed to the wall (130).

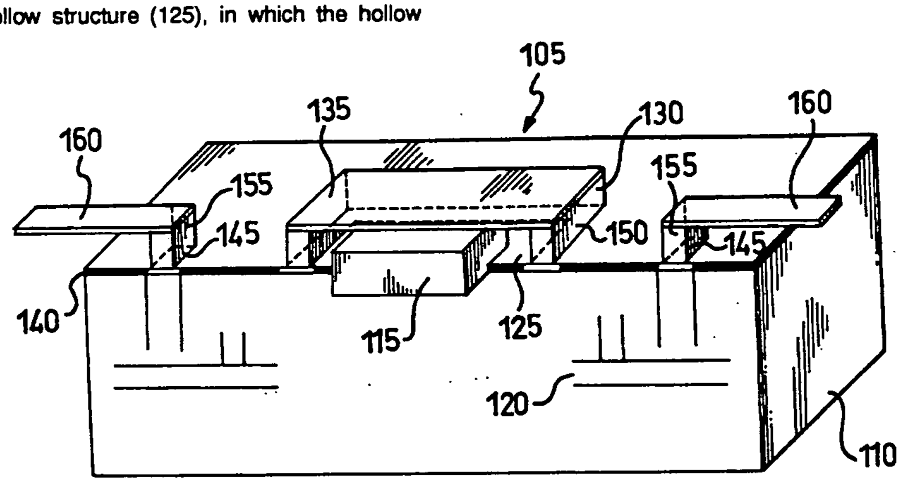

FIG.1

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Description

The present invention relates to an hermetically sealed semiconductor inertial sensor, and in particular to an inertial sensor according to the preamble of the first claim.

Inertial sensors, operable to measure a mechanical quantity, for example related to a movement of the sensor (such as its acceleration) and to produce an output signal as a function of this quantity, are utilised in various applications, for example in the automobile field to control various devices such as air bags, anti-lock braking systems (ABS), active suspensions, or in other fields such as consumer electronics, electronic processors and the like. One particular type of inertial sensor, which is extremely small and very reliable, is that made on a microscopic scale (micro sensors) on a chip of semiconductor material. Inertial sensors of this type are based on the displacement of a sensing element, movable with respect to the chip, the movement of which is converted into a suitable electrical signal. Preferably, a circuit for processing the output signal produced by the sensor should also be integrated on to this chip.

In semiconductor inertial sensors the sensitive element must be suitably isolated by enclosing it in a sealed structure in such a way as to ensure that it operates in a controlled environment; this allows the sensitive element, which has a very small mass, to move with low resistance and minimum damping in such a way as to guarantee a good sensitivity of the sensor. Moreover, the circuit for processing the output signal from the sensor requires for its utilisation to be encapsulated in a suitable container or package which protects the processing circuit from the external environmental conditions thereby guaranteeing its correct operation.

One method for hermetically enclosing a semiconductor inertial sensor consists in encapsulating it with the associated circuitry in a sealed container, for example a ceramic or metal container. This technique however is extremely expensive, which converts into a high cost of the finished product, in that the cost of the container represents the major proportion of the overall costs.

A different known technique lies in producing a hollow structure on the microscopic scale (micro cavity) to house the sensing element. This isolating method involves the micro-working of a wafer of silicon or glass which is then connected to the wafer on which the inertial sensors are formed, for example by means of an anodic bonding technique; this method makes it possible to utilise standard plastics containers of low cost for encapsulating the final product. The above described known arrangement is nevertheless rather expensive and has the disadvantage of not allowing the sensor and the associated processing circuitry to be integrated on to the same chip so that the connection step requires that the surfaces to be joined are perfectly planar (with a peak-to-trough roughness of the order of tens of Å).

The object of the present invention is to obviate the above-mentioned disadvantages. To achieve this object there is provided an inertial sensor as described in the first claim.

The inertial sensor in accordance with the present invention is reliable, simple and economical.

The hermetic sealing of the inertial sensor of the present invention can be made at the wafer level without requiring micro-working of a further silicon or glass wafer and subsequent connection operations.

This inertial sensor makes it possible also to integrate the processing circuitry on to the same chip and, possibly, to utilise a container of plastics type, which is therefore extremely economical, to encapsulate the final product.

Further characteristics and advantages of the inertial sensor according to the present invention will become apparent from the following description of a preferred embodiment thereof, given by way of indicative and non-limitative example with reference to the single attached figure (Figure 1) which illustrates this sensor in a partially-sectioned schematic view.

The figure shows an inertial sensor 105 made on a chip 110 of semiconductor material, typically silicon. The inertial sensor 105 includes a sensing element 115 constituted by a micro electro mechanical structure (or MEMS), which has a so-called seismic mass, anchored to the chip 110 at pre-established points and movable with respect thereto, the movement of which is converted into a suitable electrical signal. For example, the sensing element 115 constitutes a first electrode of a capacitor the second electrode of which is provided on the chip 110; the movement of the sensing element 115 causes a variation in the capacity of the capacitor which, in turn, is measured by a suitable circuit. The inertial sensor 105 is, for example, an accelerometer, an angular velocity sensor (gyroscope) or a vibration sensor, in which the sensing element 115 moves by the effect of the linear or angular acceleration or the angular velocity of a system (for example a motor vehicle) on which it is mounted, making it possible to measure the desired physical quantity; alternatively, the inertial sensor 105 is of resonant type in which the sensing element 115 vibrates at a frequency which varies as a function of the quantity to be detected. Advantageously, a circuit 120 for processing and amplifying the output signal produced by the sensor 105 is also integrated on the chip 110. Typically, a large number of sensors 105 and processing circuits 120 are produced in a plurality of identical areas of semiconductor wafer material, which are subsequently separated by a suitable cutting operation to form the individual chips 110.

Each sensing element 115 is hermetically sealed within a hollow structure 125 with a controlled atmosphere, containing for example air or nitrogen, typically at a pressure lower than atmospheric pressure; preferably the sensing element 115 is vacuum sealed within the hollow structure 125. In the inertial sensor 105 of the

present invention the hollow structure 125 is laterally delimited by a metal wall (bump) 130 disposed on the upper surface of the plate 110 around the sensing element 115. The hollow structure 125 is closed from above by means of a plate 135, having a size at least equal to that of the cavity 125, which is fixed (for example by welding or glueing) on to the wall 130.

The formation of the wall (bumping) 130 can be achieved by utilising various techniques. In one embodiment of the present invention, on an upper wall of the chip 110, which is clad with an insulating layer 140 (typically silicon dioxide) with known techniques of deposition, masking and etching, conductive areas (pads) 145 are formed in contact with the processing circuitry 120. During this phase there is also formed a conductive frame 150 (for example of aluminium) which surrounds the sensing element 115 and the form of which (for example circular or rectangular) varies in dependence on the form of the sensing element 115; note that the formation of the conductive frame 150 is not necessary in some processes for formation of the wall 130.

On to the conductive areas 145 and on the conductive frame 150 there is therefore grown a layer, respectively 155 and 130, constituted by a welding alloy or by another material such as nickel, covered with a layer of welding alloy; the height of the wall 130 must be greater than that of the sensing element 115, for example 10μm. The present invention lends itself to being put into practice utilising different types of welding alloys; for example if the material utilised to fix the closure plate 135 on to the wall 130 is copper, the welding alloy is advantageously constituted by nickel-gold in such a way as to form a eutectic alloy with the copper. The metal layers 155, 130 are made by means of an electroless growth process; alternatively electroplating, evaporation, dispensing and the like processes are utilised. In particular, a layer of more noble metal, for example zinc, is deposited on the conductive areas 145 and on the aluminium conductive frame 150, which impedes the formation on the aluminium oxide and hydroxide layers. The wafer is then immersed in a self-catalytic chemical solution for the growth of a layer of nickel; finally, a thin layer of gold is deposited, which protects it from oxidation and improves the quality of the welding. The above described process is particularly economical and flexible in that it is compatible with batch working of the wafer and does not require any additional screen.

In one embodiment of the present invention the sealing of the cavity 125 is achieved by utilising a polymeric layer, for example a sheet of polyimide (such a Kapton) which supports a matrix of metal sealing plates 135, for example of copper. The polymeric support layer is disposed on the wafer and the various metal sealing plates 135 are welded to the corresponding walls 130 for example by a heat compression technique or by laser heating. Subsequently the support layer is removed (by suitable solvents) and the process proceeds then to the stage of cutting the wafer and the final encapsulation stage (described hereinbelow). Alternatively, the closure of the hollow structure 125 is effected after the chip 110 has been cut and fixed to a suitable frame for the final encapsulation phase. In this case the polymeric support layer also includes tracks 160 for electrical connection to the metal layers 155 of the processing circuitry. Note that in this embodiment of the present invention the movable element is sealed in a metal cavity and is therefore advantageously screened from electromagnetic interference.

In a different embodiment of the present invention the closure of the cavity 125 is achieved by utilising a layer of copper which supports a matrix of closure plates 135 of Kapton and a third layer of corresponding copper welding frames. This structure is disposed on the wafer and the copper frames are welded to the corresponding walls 130 in such a way as to fix the closure plates 135 to these; subsequently the copper support layer is removed by means of an electrolytic stripping process.

In an alternative embodiment of the present invention the walls 130 are formed completely or partly on a support layer, for example ceramic or Kapton (with conductive frames). In this case the support layer is disposed on the wafer and the walls 130 are fixed to the upper surfaces of the chip 110, for example welded to the corresponding frames 150 or to further (lower) walls formed on the chip 110. Typically the support layer is made with apertures which allow access to the corresponding conductive areas of the processing circuitry in the final encapsulation phase; for example the support layer is constituted by a plurality of closure plates joined by means of interconnection sections, which are cut during the wafer cutting phase. This embodiment offers the advantage of reducing the problems of working the wafer due to the presence on its upper surface of the walls around the sensing elements.

The present invention also lends itself to being put into practice utilizing a metal wall 130 not constituted by a welding alloy. For example, the metal walls 130 are made in copper and are grown on a support layer of Kapton; on each metal wall 130 there is then disposed a frame of adhesive material, for example acrylic or epoxy; typically a non-polymerised adhesive is involved which reverts with temperature. This structure is disposed on the wafer and the adhesive frames are stuck around the sensing elements on the insulating layer 140 which covers the upper surface of the chip 110. Similar considerations apply if the metal wall 130 is grown on the upper surface of the chip 110 and the closure plate 135 is secured thereto by adhesive.

When the operations on the wafer and the associated testing are completed the chips 110 are separated with a cutting operation. Each chip 110 is then fixed to a suitable frame by welding with a low-melting alloy, for example lead-tin, or by glueing with a suitable adhesive. In the embodiment illustrated in the drawing, the tracks 160 connected to the conductive areas 145 of the

processing circuitry by means of the metal layers 155 constitute the connection electrodes of the device. Alternatively, the conductive areas 145 are connected by means of thin metal wires, for example of gold to corresponding electrodes (wire bonding); typically, the metal wires are welded with a low melting alloy, on the one hand, to the conductive areas 145 and on the other to the internal ends of the electrodes, with a so-called thermosonic process which provides for the simultaneous application of heat and ultrasound. The assembly thus formed can be used directly in cases in which it is inserted into a controlled environment system, such as hard-disc drivers. Alternatively, the assembly is mounted in a suitable mould into which a plastics material is injected in liquid state, for example a thermosetting epoxy resin. After polymerisation of the resin there is obtained a structure which includes an insulating body in which the above-described elements are embedded and from which project the electrodes for connection to an external circuit.

Claims

1. An inertial sensor (105) having a sensing element (115) formed on a surface of a chip (110) of semiconductor material and movable with respect to the chip (110), the sensing element (115) being enclosed in a sealed hollow structure (125),
 characterised in that
 the hollow structure (125) includes a metal wall (130) disposed on the said surface about the sensing element (115), and a closure plate (135) fixed to the wall (130).

2. An inertial sensor (105) according to Claim 1, in which the wall (130) is constituted at least partly by a welding alloy.

3. An inertial sensor (105) according to Claim 1 or Claim 2, in which the closure plate (135) is made of a metal material.

4. An inertial sensor (105) according to Claim 1 or Claim 2, in which the closure plate (135) is made of a polymeric material.

5. An inertial sensor (105) according to any of Claims from 1 to 4, further including a processing circuit (120) formed in the said chip (110).

6. An inertial sensor (105) according to any of Claims from 1 to 5, in which the inertial sensor (105) is encapsulated in a plastics container.

7. A method of enclosing, into a sealed hollow structure (125), the sensing element (115) of an inertial sensor (105) having a sensing element (115) formed on a surface of a chip (110) of semiconductor material and movable with respect to the chip (110), characterised in that it includes the steps of:

 a) forming a metal wall (130) on the said surface around the sensing element (115),

 b) fixing a closure plate (135) to the wall (130).

8. A method according to Claim 7 in which the metal wall (130) is at least partly constituted by a welding alloy, and step b) is formed by welding the plate (135) on to the wall (130).

9. A method according to Claim 7 or Claim 8, in which step a) is performed by forming a conductive frame (130) around the sensing element (115) on the said surface and growing the wall (130) on the frame (150).

10. A method according to Claim 9, in which the step of growing the wall (130) is performed by means of an electroless growing process.

11. A method according to any of Claims from 8 to 10, in which step b) is performed by disposing on the chip (110) a layer which supports the closure plate (135), welding the closure plate (135) to the wall (130), and removing the support layer.

12. A method according to Claim 11, in which the support layer is made of a polymeric material.

13. A method according to any of Claims from 8 to 10, in which step b) is performed by disposing on the chip (110) a layer which supports the closure plate (135) and a metal frame, welding the metal frame to the wall (130), and removing the support layer.

14. A method according to Claim 13, in which the support layer is made of a metal material.

15. A method according to any of Claims from 7 to 14, further including the steps of forming metal layers (155) on corresponding conductive areas (145) in contact on the said surface with processing circuitry (120) formed in the said chip (110), and welding metal tracks (160) on to the metal layers (155).

16. A method of enclosing, in a sealed hollow structure (125), the sensing element (155) of an inertial sensor (105) having a sensing element (115) formed on a surface of a chip (110) of semiconductor material and movable with respect to the chip (110), characterised in that it includes the steps of:

 a) forming a metal wall (130) on a support layer,

b) fixing the wall (130) on to the said surface about the sensing element (115).

17. A method according to Claim 16, in which the metal wall (130) is at least partly constituted by a welding alloy and step b) is formed by welding the wall (130) to a metal frame (150) formed around the sensing element (115) on the said surface.

18. A method according to Claim 17, in which the support layer is ceramic.

19. A method according to Claim 16, in which step b) is formed by disposing a frame of adhesive material on the wall (130) and securing the wall (130) to the said surface by adhesive.

20. A method according to Claim 19, in which the support layer is constituted by a polymeric material.

21. A method according to any of Claims from 16 to 20, in which the support layer includes a plurality of apertures in correspondence with conductive areas (145) in contact on the said surface with processing circuitry (120) formed in the said chip (110).

22. A method according to Claim 21, in which the support layer is constituted by a plurality of closure plates (135) on each of which the said wall (130) is formed, connected together by means of interconnection sections.

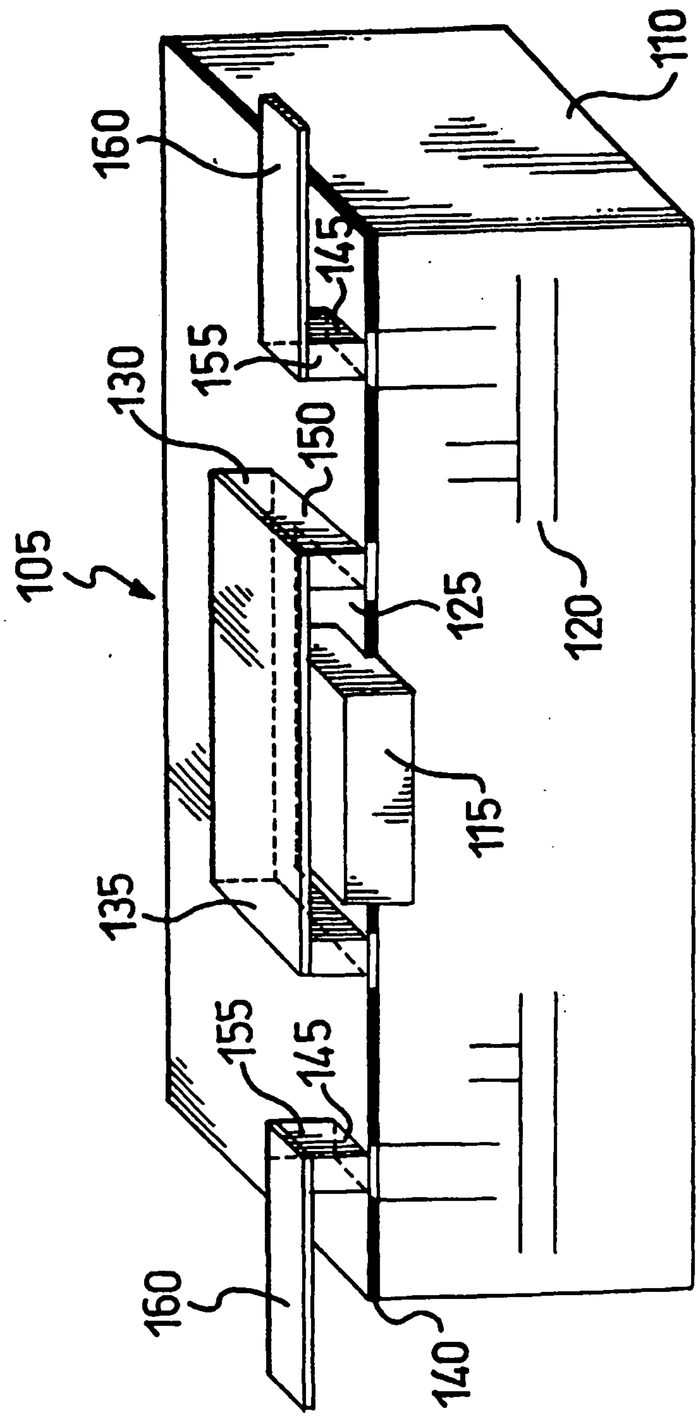

FIG.1

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EUROPEAN SEARCH REPORT

Application Number
EP 96 83 0654

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	WO 96 39632 A (ANALOG DEVICES INC) 12 December 1996 * page 5, line 21 - line 35 *	1-9,16, 17	G01P1/02 G01P15/08
Y	* page 6, line 6 - line 25 *	14	
A	* page 8, line 11 - line 35 * * figures 2,6,7 * ---	10,18,19	
X	EP 0 732 594 A (SIEMENS AG) 18 September 1996 * column 3, line 6 - column 4, line 37 * * column 4, line 55 - column 6, line 41; figures 4,5 * ---	1,7, 11-13, 15,16, 20,21	
Y	US 4 528 583 A (TE VELDE TIES S ET AL) 9 July 1985 * column 8, line 51 - column 10, line 24; figure 11 * -----	14	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

G01P

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15 May 1997	Nessmann, C

CATEGORY OF CITED DOCUMENTS

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